WETLAND RESTORATION USING A DYNAMIC 3D GRAVEL BEACH SYSTEM

PROBLEM STATEMENT:

Lake level regulation has created wetlands boarding seasonal aquatic nearshore environments across the North Shore of Flathead Lake. Historically these shore land landscapes were inundated during spring run-off and subsequent lake level rise. Decades of maintaining an extended full pool season for months has concentrated wave power at a single lake level elevation. The result has been a steady loss of fringing wetlands due to wave erosion.

PROJECT GOALS:

The goal for this particular project is to create a dynamic 3D gravel beach system that will 1) stop the loss of existing wetlands due to wave erosion 2) provide a natural transition from the nearshore aquatic environment into a fringing wetland that maintains the hydrologic connection with the lake. These hydraulic processes are 3 dimensional in nature characterized by a dynamic system that operates in both in the cross-shore as well as in the longshore. Therefore, the design goal is to first identify the processes that currently shape the nearshore environment and then design a gravel beach system that will shift the end result from a net erosion dominated system to a net depositional system. Hence, the landscape will necessarily be composed of complex curved shorelines rather than conventional 2-dimensional straight rip-rap.

PROJECT LOCATION, BOUNDARIES and ACCESS:

The project is located on the Eastern side of Somers extending to the Western boundary of the USFW Waterfowl Production Area (WPA) (Fig.1). The project has been separated into 3 sections to accommodate differing stakeholder ownership and potential investment in the solution (Fig. 2). An access road ends at an open area near the juncture between section I and II (Fig. 2). This open area could be used as a staging area for gravel and wood material during construction. A temporary path will need to be made between the staging area and the lake bed (Figs. 3 & 4). Small (6” diameter) logs will need

Figure 1. Site location map. Yellow lines point to site boundaries along the shoreline.

to be laid down over the vegetation along this path with pit run sand and gravel dumped on top . These materials will be removed and cleaned up after construction. This approach has been used with great success on the WPA

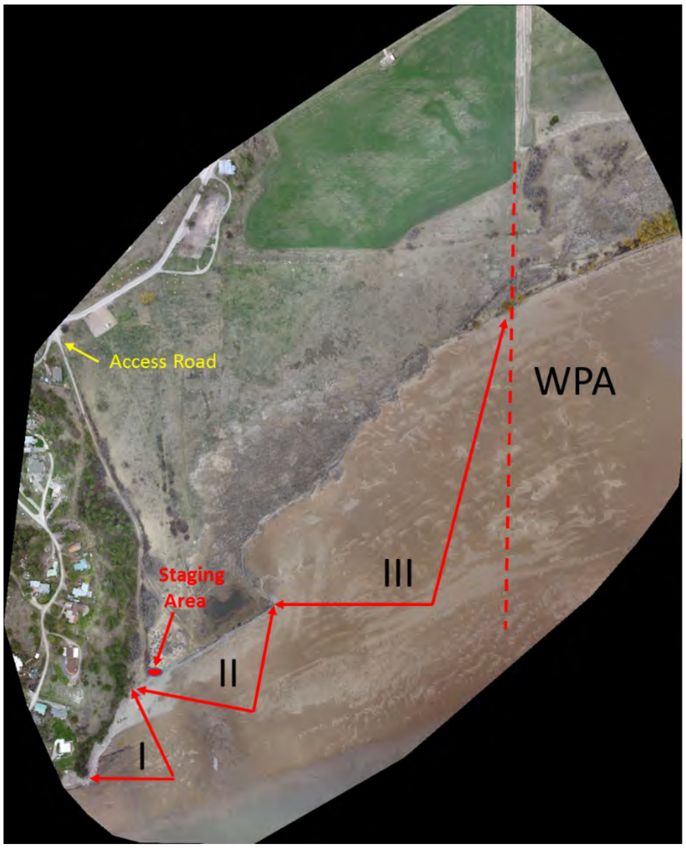

Figure 2. An aerial photograph taken in April 4th, 2016 using a fixed wing drone shows the access road, staging area, three sections of the project and boundary with the USFWS Waterfowl Production Area (WPA)

Figure 3. A photograph of the potential staging area.

lands to the East. Once removed the grasses will grow back within one season in this minimally disturbed area. A ramp will be made with pit run material to allow equipment to drive onto the lake bed. Gravel material will be dumped on the staging area, loaded into a tracked truck with an excavator and then hauled to the placement site. This process can be completed any time the lake is drawn down. Maximum drawdown occurs April 30th. As the lake is drawn down (a process that begins Sept. 15th each year), the wetland drains towards the lake (Fig. 4). The drainage path is inferred from wet sands seen in aerial photographs of the lake at maximum drawdown lake levels. Two wet areas on the exposed lake bed are shown (Fig. 4). These areas will require the tracked truck to deliver material. Because of the draining water, these areas often do not freeze solid enough to support dump truck delivery of material.

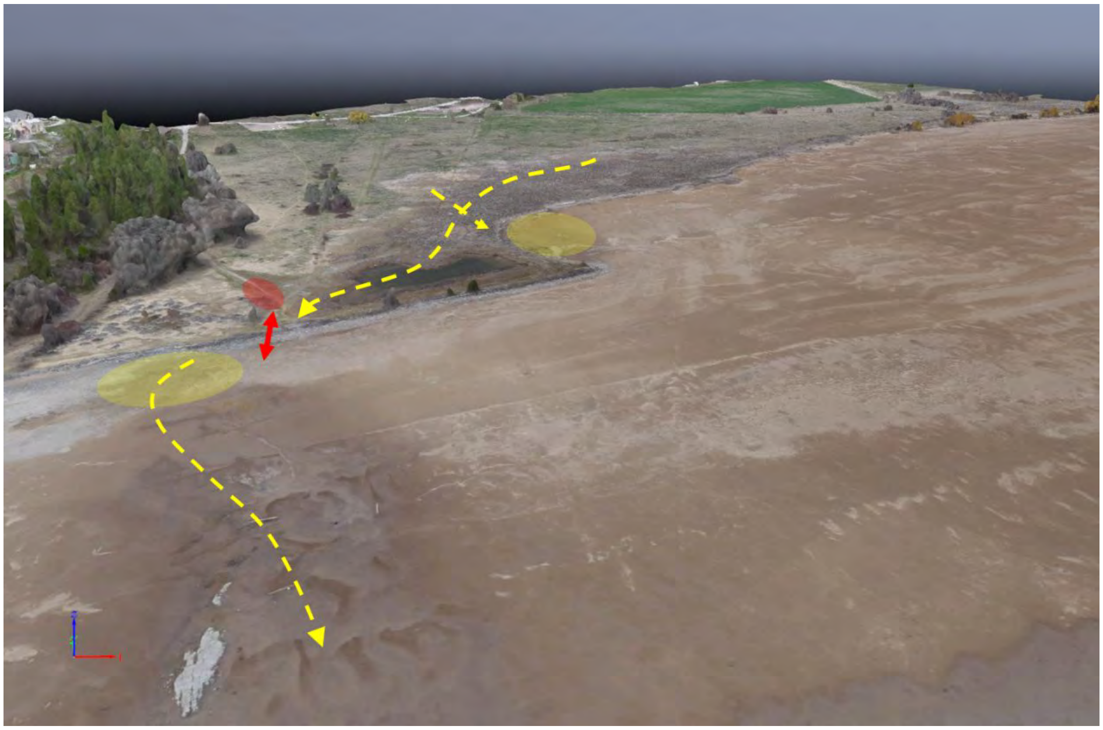

Figure 4. An aerial photograph of the lake bed that shows dry versus wet areas. The yellow dotted lines show inferred drainage patterns. The yellow ellipses show areas that will be wet in the winter and may not freeze well or if ice forms at that surface it will insulate the saturated sediments below resulting in mud. The red arrow and ellipse shows the location of a potential staging area and path to the lake bed.

NATURAL PROCESSES SHAPING THE LANDSCAPE:

Aerial imagery collected during 2016 lake draw down of the exposed lake bed (April 4th, 2016) shows a system of large scale (~25 m spacing) parallel sand bars (Fig. 5). These bars are formed by wave action during full pool and reflect the approach of wave energy relative to the orientation of the shoreline. This is important information for the design of the beach system. Aerial imagery collected during 2016 summer full pool (August 8, 2016) shows several additional important pieces of information for the design (Fig. 6).

First, the shoreline is distinctly shown as a light colored line composed of driftwood and logs separating the open water from the fringing wetland. Second, the plants of the wetland have distinct coloration due to the types of plants and amount of water they are growing in (Fig 6 yellow and red lines). The area between the black line (the line 20 horizontal feet landward of the mean annual high water elevation) and the red line is composed mainly of cattails growing on substrate below 2893' full pool. The red line represents the furthest extent landward of the regulated lake level. If one walks through these cattails from the current shoreline towards the redline one will initially encounter knee deep water. As one continues to walk landward towards the yellow line, soggy wet grasses are typical of the wetland transition to upland vegetation (Fig. 6).

Figure 5. An aerial photograph of the site depicting various areas of interest and with blue arrows showing directions of wave approach inferred from the orientation of different sets of multiple-parallel bars visible on the lake bed.

Lastly the coloring of the lake bed shows distinct offshore contours between light and dark areas. These color differences are due to waves eroding the lake bed and nearshore currents that deposit wetland soils in a crescent shape (Fig. 6). The offshore dotted blue line in figure 6 follows a lakebed contour formed by breaking waves. This is the zone where waves first break due to a change in water depth and where the reflected waves from the log shoreline meet. Comparison between the aerial image in figure 5 and figure 6 reveals how much shoreline has actually eroded away this summer (keep in mind that the linewidth is about 10 feet at this resolution). The orange arrows indicate a circulation pattern of nearshore currents that help shape the curved embayments and pointed crest of the depositional horn (Fig. 6). This classic shoreline morphology is caused by wave action and associated nearshore currents and hence provides information that can be used to design and build a beach system that will “tune” the waves, shifting the net outcome from erosion to deposition. In time the depositional horn will re-vegetate naturally with an array of wetland plants mainly bulrush while the embayments will support growth of aquatic plants.

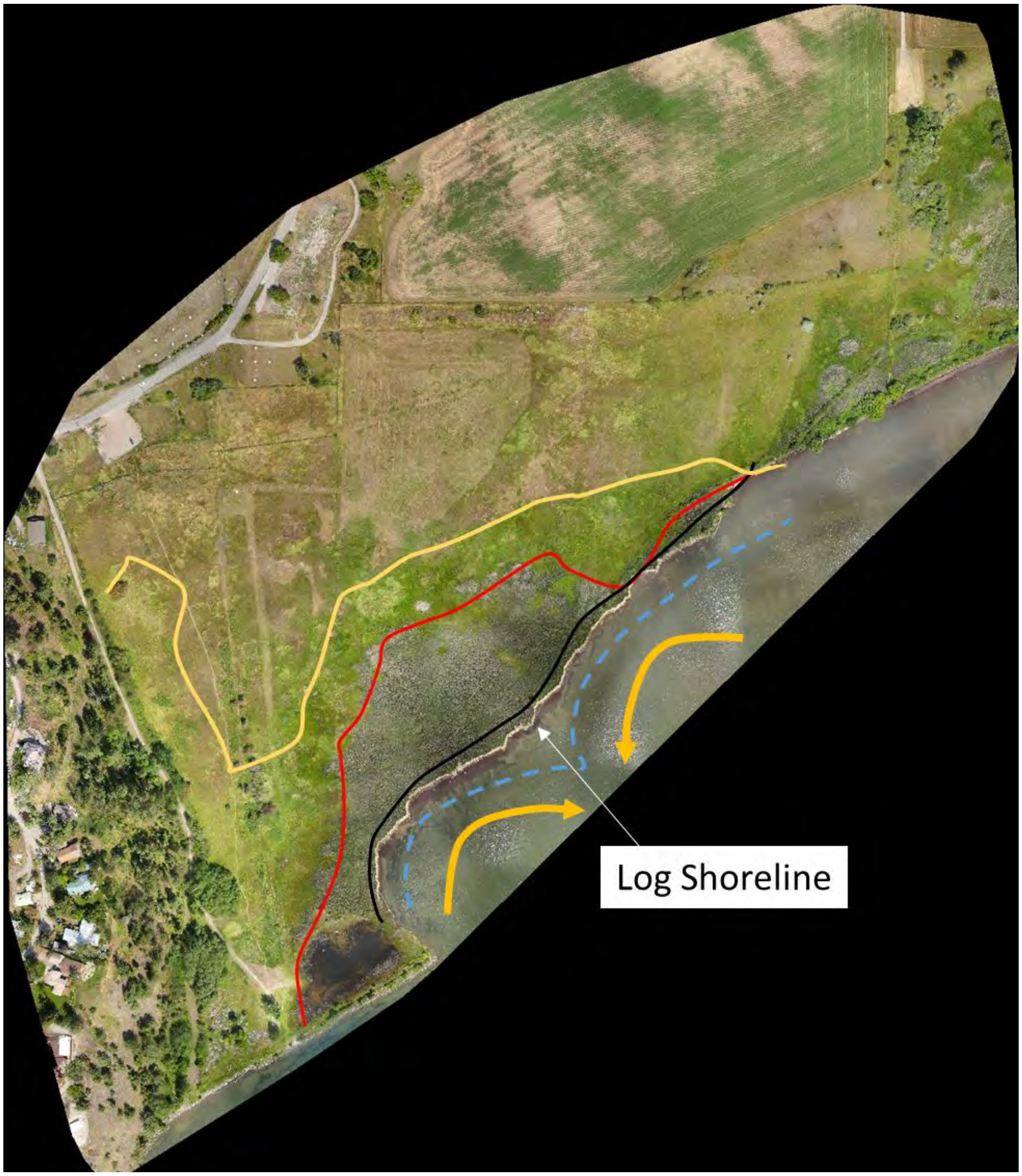

Figure 6. An aerial photograph taken by a fixed wing drone on August 8, 2016. The log shoreline shows up distinctly (it is not drawn in) demarking the 2893 full pool line separating the lake from the wetland. The black line is an approximate 20 ft offset required by regulatory permits. The red line is the border between that area of the wetland that has substrate below 2893' and dominated by emergent vegetation (mainly cattails) from the wetland area dominated by sedges and rush types of vegetation that grow well on saturated soil. The yellow lines approximately separate the wetland area from the beginning of the transition zone into upland plant species. The dotted blue line demarks an offshore contour between dark water and lighter lake bed offshore and the orange arrows depict circulation patterns inferred from the shoreline morphology and blue line as explained in the text.

DESIGN ELEMENTS:

1) *Gravel Beach versus Seawall*

Identifying the landscape features described above and linking them to various wave and nearshore current processes provides the rationale for the various design elements of the complete 3D gravel beach system. The first and most important design element is to force waves to completely break and then swash up a gravel beach face. This natural process dissipates the wave energy through a variety of hydraulic process from turbulent water motion and friction to energy used to transport gravel. In addition the swash losses water that percolates into the beach matrix as the wave swash reaches its final extent (Fig. 7). During this process gravel is deposited on the beach face and piled as high as the waves can reach balanced by the amount of sediment available to work with. This series of wave breaking related processes keeps the wetland connected to the lake while simultaneously stopping erosion. During large storms in combination with lake seich motion waves will overtop the gravel beach and spill into the marsh depositing fine sediment and organic material. These overwash events result in a complex mosaic of habitat diversity within the marsh itself. In contrast boulder rip-rap and seawalls reflect wave energy resulting in scour to the lakebed and accelerated erosion to neighboring unprotected properties as occurred to the marshlands bordering the Eastern end of the rip-rap dike on this site (Fig. 7).

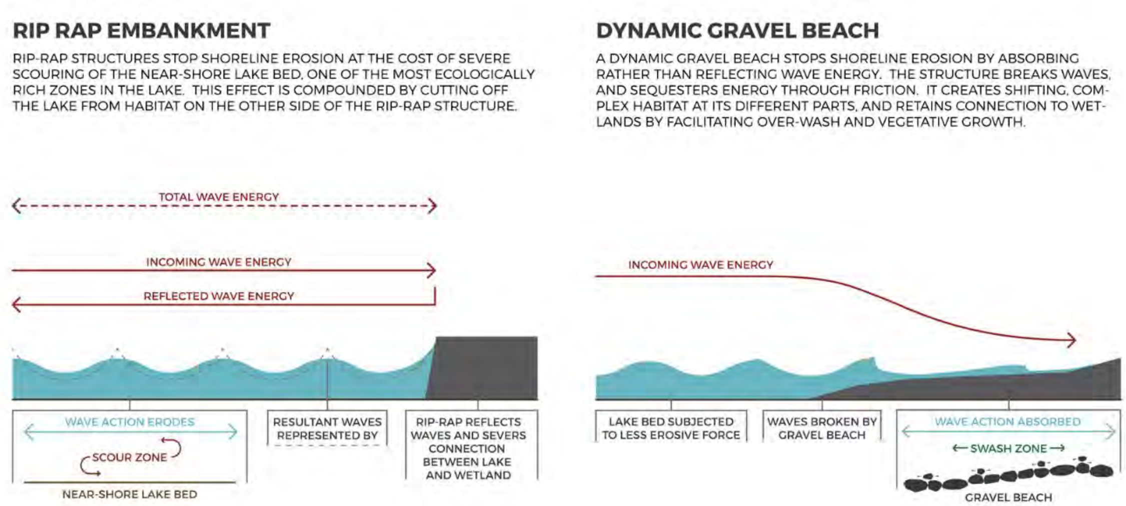

Figure 7. A schematic explaining relationship between wave interaction against a seawall and wave breaking on a beach (Figure created by Peter Obermeyer).

A key element in a beach design is to use the proper range in gravel size so that waves can move the material but not wash it away. With the proper size distribution waves will move the gravel around forming a dynamic equilibrium profile (Fig. 8 top). The larger rocks will move down the profile and form a "step" at the point where waves break and plunge onto the subaqueous portion of the profile. This process of wave breaking and plunging will dissipate most of the wave energy followed by a "swash" of water that will run-up the beach face carrying smaller gravel with it and forming a beach crest above the water line (Fig. 8 top). The backwash flows into the beach gravels and back towards the step where it meets the next breaking wave.

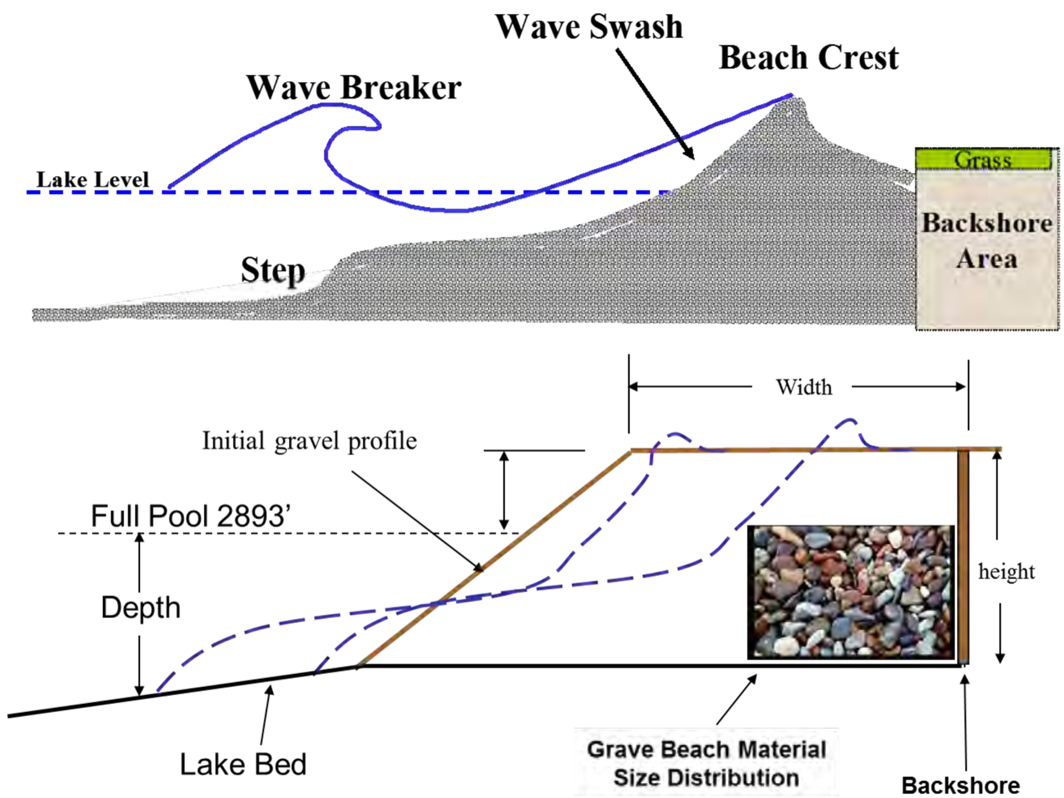

Figure 8. A schematic showing a wave breaking at the beach step and swash run-up to the beach crest (Top). This process keeps wave action away from eroding the backshore area which is the design goal for a gravel beach. The schematic on the bottom shows the design elements to consider so that the waves can work and rework the gravel forming many different beach profiles while at the same time keeping the wave action away from the backshore. A key element to allow this dynamic behavior to exist is the size range of the gravel material used.

The design challenge is to provide the waves enough gravel over the proper range in size relative to the wave forces the shoreline is subjected to so that the step and beach crests can be formed from storm to storm while still keeping wave energy away from the backshore environment (Fig. 8 bottom). In the case of the marsh shoreline our goal is to take a very minimalist approach where by enough gravel is used to maintain a dynamic gravel beach during most wave events but allows the beach to be overtopped during large storms. This is designing on the edge but is a necessary requirement if the processes that shape the fringing wetland are to be maintained as well.

The dotted blue line in figure 6 shows the approximate location of these wave breaking and swash processes along the marsh shoreline of section III. Longshore transport of gravel and sand forms the depositional horn between two cuspate embayments. Currents in the shallow offshore region will also circulate within the embayments carrying and depositing silts and organic material (peat) in a similar pattern (Fig. 6). This pattern of sediment deposition and wave breaking is what we want to enforce. By keeping the shape of the paired embayments and depositional horn we can both stop erosion while at the same time encourage the waves to deposit more fine sediment and organic material (logs to small wood chips that turns into peat). This will, in turn, result in natural revegetation by riparian, wetland and aquatic plants within the area of section III that is currently eroding and composed mainly of a barren lake bed.

2) The Spit

The second important design element is the orientation of the shoreline to work with sections of shoreline that are not continuous as is the case for the shorelines between sections II and III (Fig. 5). These ends or discontinuities in the shoreline planform are where erosion can be the highest. They are similar to the end effects that occur along rip-rap and seawalls, in fact that is precisely the situation we have. Section II is fronted by an existing rip-rap that is stopping erosion to the property behind it but at the same time exacerbating the erosion problem to the East along section III.

Common to many natural coastlines are curved hook shaped shorelines referred to as Spits (Fig. 9). They form at river mouths and along some natural discontinuities in shoreline extent. Spits can perform several functions if designed properly and the proper sized material is used.

Figure 9. An aerial photograph of a gravel spit built in 2007 on the North Shore of Flathead Lake. The main body of the lake is towards the bottom

They can be designed to control the direction of sediment transport, to enhance deposition of fine sediments and to radiate wave energy away from ends of rip-rap or natural discontinuities in a shoreline. In this case we want a spit to radiate wave energy back out into the lake, interact with the incoming waves such that gravel moves from the East end (border between section III and II) and cause silts and organic material to deposit in the embayment behind it as well as the small embayment inside (Fig. 9). Gravel spits have been used in several locations (3) along the North Shore WPA project. They will begin trapping logs and wood debris including peat material within the first full pool season (Fig 10). Natural colonization by riparian and wetland plants occurs rapidly thereafter and continues for years to come (Fig. 10). The spits on the WPA have been continually changing and growing new wetland habitat for over a decade now while at the same time protecting the neighboring shorelines from wave erosion.

Figure 10. A time-series of photographs taken of the gravel spit built on the North Shore of Flathead Lake WPA near Bigfork. Photograph A was taken in June of 2007 just after construction and a few weeks into its first full pool season. Photograph B was taken in September 2007, note the deposition of a large amount of peat material and logs. Photograph C was taken in April of 2009 showing initial establishment of vegetation. Photograph D was taken on August 8th 2016 showing well established marsh wetland formed in the embayment of the spit.

3) Root-wads and logs

Root-wads, logs and large woody debris in general are common elements of rivers and lakes. The Flathead River erodes banks upstream and delivers this material to Flathead Lake where waves push the material towards the shoreline. The root-wad is the first part to encounter the shallow lake bed causing to anchor while waves push the log-stem further towards shore. This is why we often observe logs stranded offshore with the root-wads pointed towards the lake. If one walks along the shoreline of Flathead Lake between Somers and the river mouth, one will see a solid mass of logs. Often two or more logs get pushed up against the shoreline forming an A-frame. This A-formation of root-wads and logs greatly disrupts wave action and ultimately slows the longshore transport of gravel along the beach. Likewise, it results in differential patterns of localized erosion and deposition (scour near the root wad deposition behind within the A-form. This is a micro-pattern (compared to the macro-size spit, depositional horn and embayments) of erosion and deposition of woody debris creates a very complex shoreline and dynamic shifting mosaic of habitat right at the transition from lake to fringing wetland. Moreover it provides a dynamically stable shoreline composed of much less material than a beach without wood. We have used this approach with great success along the North Shore by bringing root-wads and logs into the design and placing them in strategic locations (Fig. 11).

Figure 11. A photograph showing the placement of root-wads with attached 20 ft stems in an A-formation. The logs were then buried in gravel.

DATA REQUIRED for DESIGN

We used a variety of airborne remote sensing data to provide the information required to determine how much material needed to create the dynamic 3D beach system proposed. In

2009 the MT department of Natural Resources flew the Flathead Valley collecting LIDAR data which is high density elevation information from which a Digital Elevation Model (DEM) can be built (Fig. 12). We used airborne imagery collected from a small drone (https://www.sensefly.com/drones/ebee.html) operated by WaterShed Consulting a MT company located in Missoula (http://www.watershedconsulting.com/home).

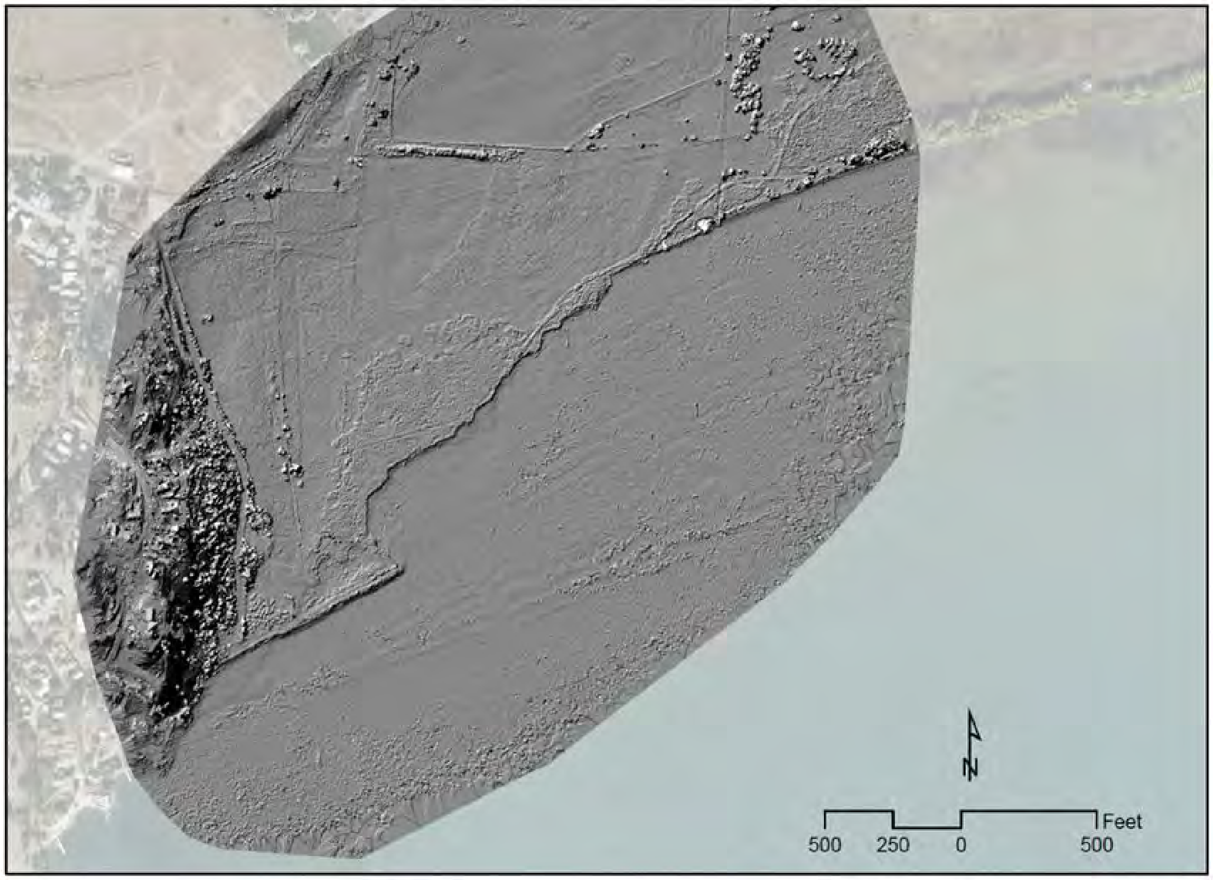

Figure 12. An aerial view of the site with a gray shade image made from the Lidar data used to measure the elevation of the lake bed.

We combined these remote sensing datasets in ArcGIS to create contour maps of the site (Fig. 13). And we used the DEM to extract elevational profiles of the existing lake bed from any transect location that we want (Figs. 14). That data was then used to plot elevational cross-sectional profiles from which beach designs could be developed in 2D and then transferred to Plan View (3D) to yield total volumes of material required for any specific design option (Fig. 15).

We worked with Chris Barnes from Bruce Boody Landscape Architects Inc. in Whitefish to create the renderings of the designed beach system (Figs. 16-19). The plan view design for the project (Fig. 15) shows the lineal feet and volumes of gravel material required for 6 separate sections of the beach. Sections 1 and 2 are equivalent to sections I and II respectively as shown in figure 2. Section III in figure 2 is divided into 4 sections beginning with section 3, which is the spit. Section 4 is the embayment behind the spit. Section 5 is the depositional horn. Section 6 is the West embayment (Fig. 15).

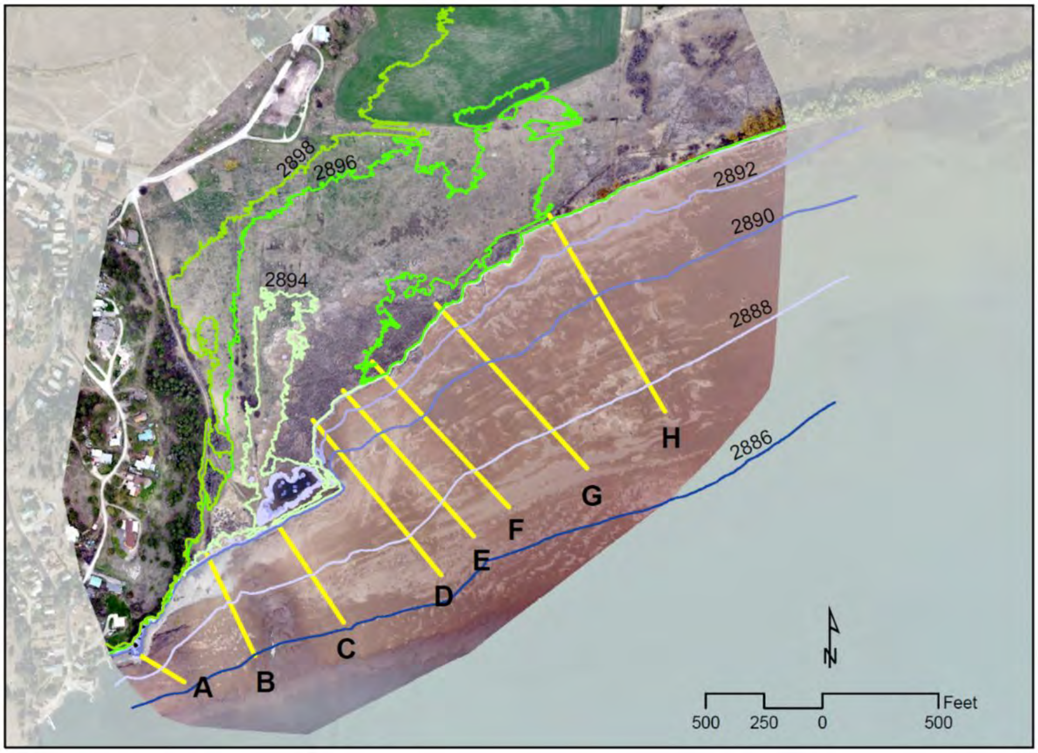

Figure 13. An aerial photograph of the site with elevational contours laid on the beach from the lidar data shown in figure 12. The yellow lines show locations of transects of current lake bed elevations. Profile plots of that transect data is shown in figure 14.

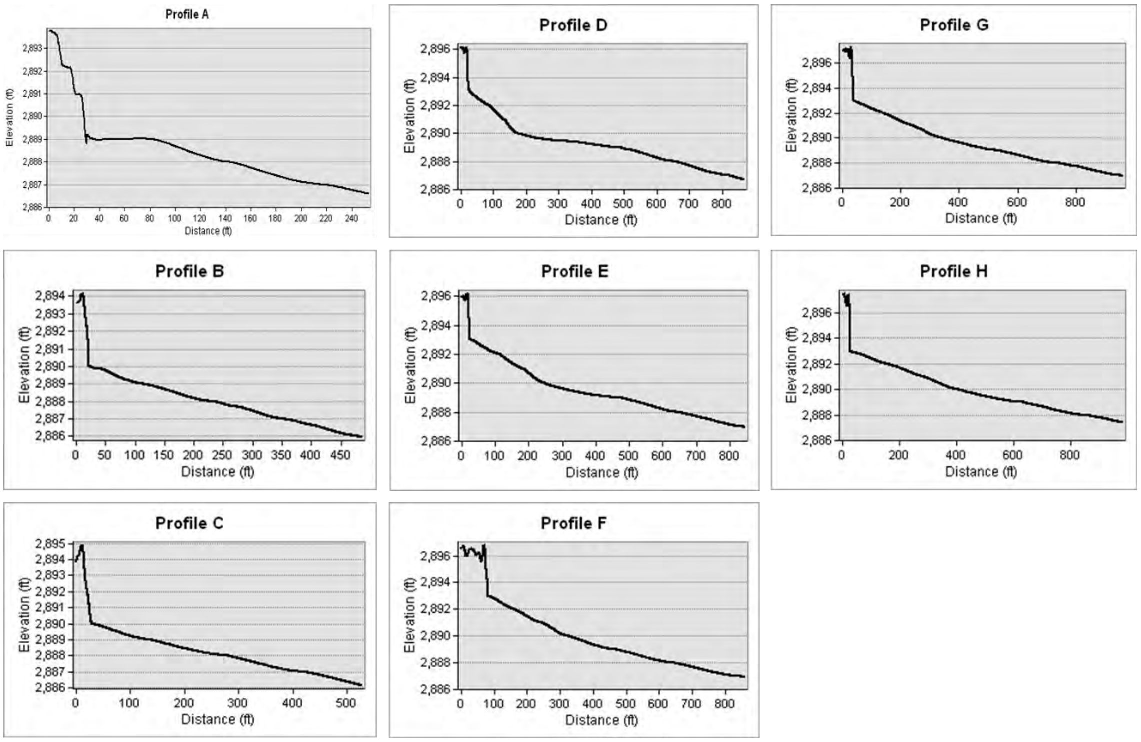

Figure 14. Plots of shoreline and lake bed elevation at transect locations shown in figure 13.

FINAL RENDERING of PROPOSED WETLAND AND GRAVEL BEACH SYSTEM:

Section 1

Section 1 shoreline forms the Western edge of the project and backs up to the steep slopes of Somers (Fig. 15). This shoreline is 451 feet long and will require 902 cubic yards of gravel material which is 2 cy/ft on average. Some areas will require a bit more others less depending on the existing supply of cobble/gravel material. Because the orientation between the shoreline and the dominate range of wave approach forms a steep angle between wave breaking and the beach, gravel in this area will transport Northward. In order to minimize the amount of gravel required and limit the longshore transport a mix of larger gravel (3” to 6” diameter) cobble will be used to form this section of cobble/gravel beach (Fig. 16 top). The exposed sloped fill of material will be 20 feet wide extending from the lake bed to an elevation of 2894’ (one foot above full pool). The width of the top will vary as a function of offshore and current beach slope. A top layer of pit run sand and gravel could be placed on top and seeded with native grasses if desired, ora second layer of smaller beach gravels could be laid on top to form a more desirable recreational beach. This would require additional root-wads and logs to control longshore transport of gravel.

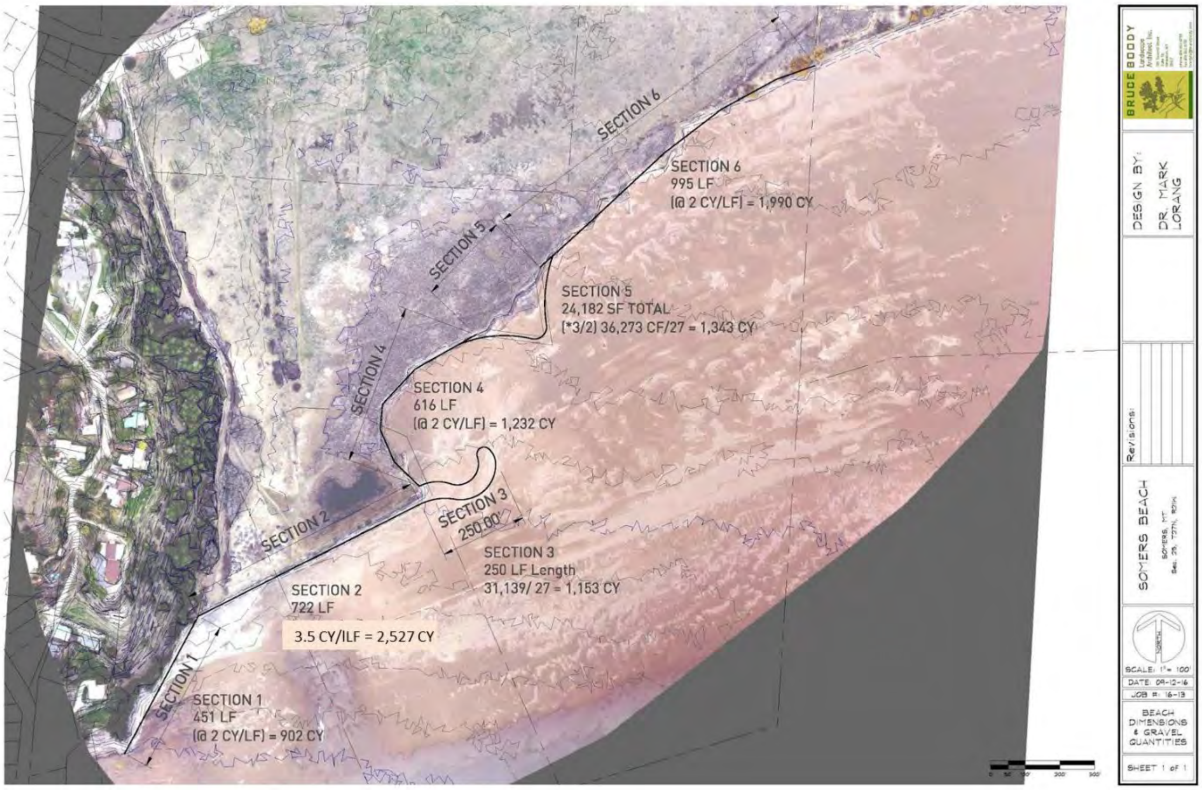

Figure 15. A planview of the beach design showing 6 different sections.

Section 2

The shoreline along section 2 makes a relatively sharp angle as it trends nearly East-West (Fig. 15). A large root-wad A-formation will be constructed at this location to prevent scour of the beach as well as discourage foot traffic from section 2 to section 1. The shoreline of section 2 is currently armored with large rip-rap. Because erosion is not an issue along section 2 the design goal is to create a recreational beach (Fig. 16 bottom). This section of beach will be constructed of two layers forming what is called a "perched gravel beach" (Lorang 1981). The first perched gravel beach was constructed in 1987 along the East Shore of Flathead Lake near Yellow Bay (Lorang 1991) and is still functioning beautifully after 30 years providing backshore protection from wave erosion. The seawall constructed at the same time has completely failed as well as the current rip-rap by allowing waves to crash against the backshore and cause erosion (please email Mark Lorang at mark@freshwatermap.com if you would like to watch videos of waves breaking on both shorelines during a recent very large storm).

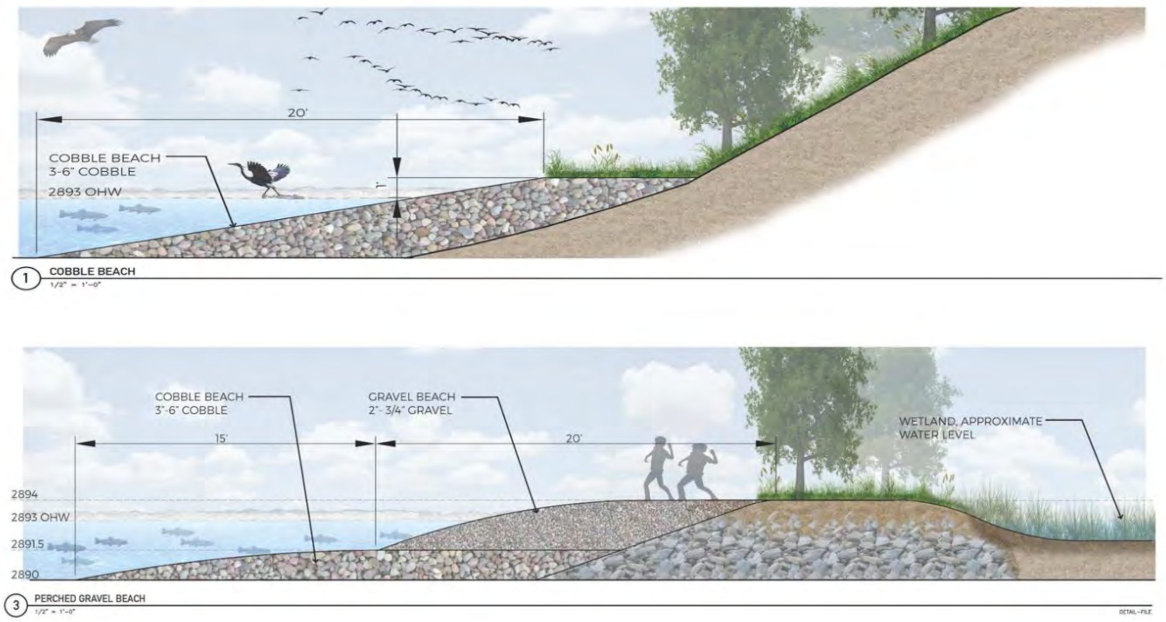

Figure 16. Landscape architectural renditions drawn to scale of dynamic beach system for section 1 (top) and section 2 (bottom).

The lower layer of the perched gravel beach will be constructed with the same gravel/cobble mix of (3"to 6" diameter) material covering the toe of the existing rip-rap to a depth of 1.5 feet (Fig. 16 bottom). A layer of mixed beach gravel (2" to ¾" diameter) material will be placed on top (Fig. 16 bottom). The beach will be 35 feet wide from the lake bed to the rip-rap along the 722 linear feet of section 2, requiring 3.5 cubic yards/ft of gravel for a total of 2,527 cubic yards of place gravel and cobbles.

Gravel transport will be bi-directional along section 2. Waves from the East will transport gravel to the East and waves from the both the South and West will transport gravel to the East although at different rates. Ideally, bi-modal transport will be net zero but this is unlikely over a single full pool season and is dependent on the dominance of storm wave direction over the full pool time frame. Over the long term (3 to 4 years to decades) the net transport may come much closer to zero (equal in both directions). The design presented is a minimum because erosion is already controlled by the underlying rip-rap. Hence the width of the beach will vary greatly. It could swing from end to end leaving the center beach very narrow or it could break into smaller cuspate cells. My suggestion is to watch the beach over time and take an adaptive management approach consisting of bringing in more material and logs until the desired dynamic equilibrium beach width is achieved. Alternatively, the beach could be made much wider (~ 20 ft) which would essentially provide a supply of gravel greater than the ability of the waves to transport. This would require doubling the volume of gravel.

Sections 3-6

Sections 3, 4, 5, and 6 (Fig. 15) compose the remaining portion of the project. Section 3 is the spit. Section 4 is the first cuspate embayment behind the spit. Section 5 is the depositional horn. Section 6 is the Westward cuspate embayment extending to the border with the USFWS Waterfowl Production Area (Fig.15)

Spit

The spit has a special recurved shape that forms several functions. The lakeward side is convex out towards the lake to create a breaking angle with the dominant waves coming from the South and West. These waves will break at an angle that will force gravel transport from the spit area Westward along section 2. Waves from the West will transport gravel Eastward along section 2 perched beach until they reach the convex recurved section of the spit which reduces the breaking angle to nearly zero which in turn results in the along shore transport of gravel to go to zero as well. Hence the design goal is to contain all of the gravel forming the recreational perched gravel beach within section 2. The spit then curves back towards the North creating a cuspate embayment on the North side.

The spit will be constructed with 1,153 cubic yards of material composed of (3" to 6" diameter) gravel and cobbles. The outer spit will require a much higher percentage of 6 "cobbles composing the outer edge while the inner core will be made with pit-run sand and gravel to allow trees to root and grow on the spit (Fig. 17 top and Fig. 15). The shape will cause plunging breakers to occur during storms and in so doing result in what energy is not dissipated through breaking (~ 20%) to radiate out into the lake. Imagine throwing a rock into a still pond and watching the waves radiate out from the center splash. The energy dissipates along the concentric rings as they expand away until waves cannot be detected at all. The same thing happens at the spit but radiating wave energy is masked by the

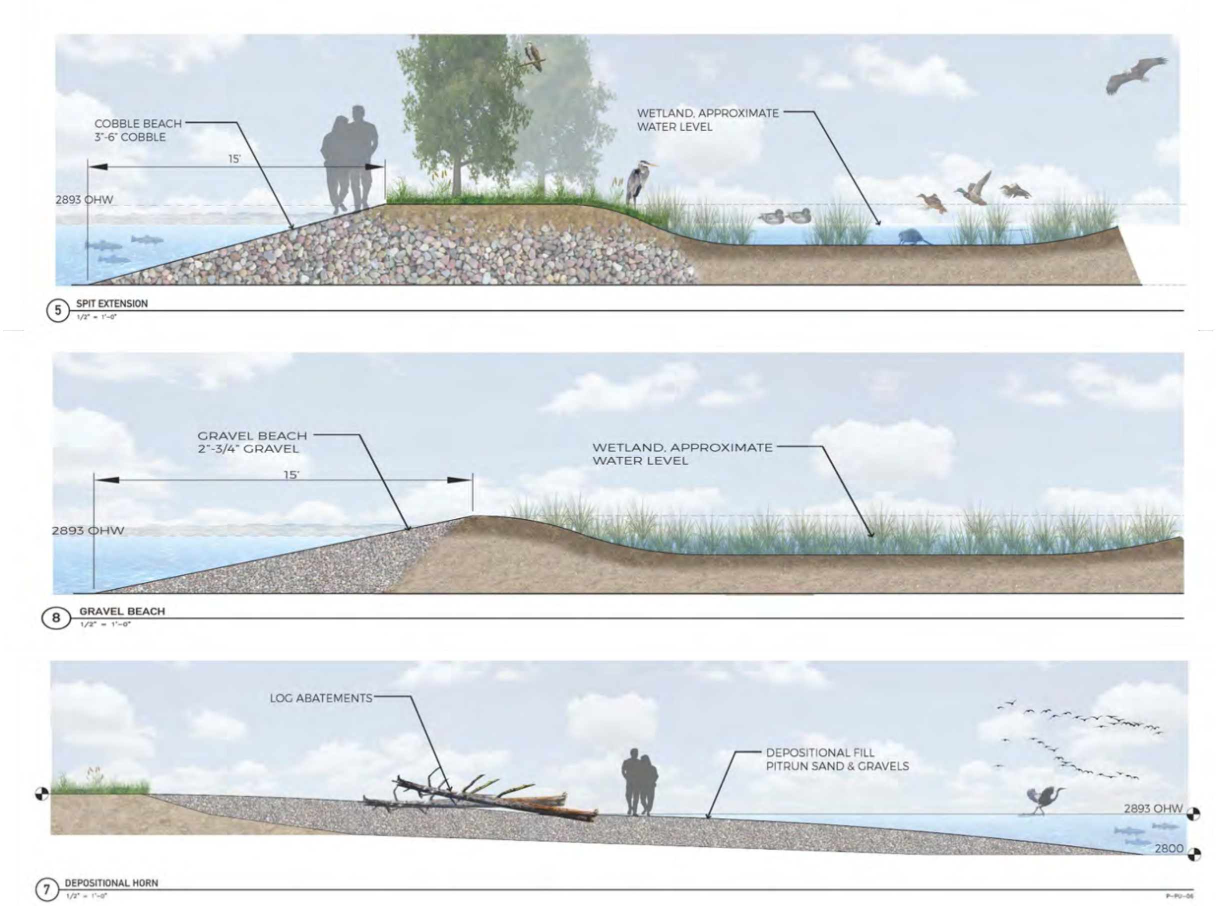

Figure 17. Landscape architectural renditions drawn to scale of dynamic beach system for spit in section 3 (top) and the shore attached beach in sections 4 and 6 (middle) and the depositional horn in section 5 (bottom).

incoming waves which are so much larger. If the spit was constructed on a vertical wall, then one would be able to see the reflected waves because vertical walls reflect 100% of the wave energy. Waves will radiate and wrap entirely around the spit (a process called refraction) and into the cuspate embayment although they will be very small and hard to see amongst the incoming waves that do not encounter the spit. These waves will actually push wood and other organic debris into the cuspate embayment on the North side of the spit and over time this area will begin to look like the embayment shown in figure 10. The whole embayment of section 4 behind the spit will collect fine sediment, wood debris and organic material and over time begin to fill in allowing aquatic and emergent marsh vegetation to colonize. This process will continue filling the embayment behind the spit until it reaches the end point where wave energy will dominate and not allow deposition to occur. Material then will be driven shoreward until it reaches the gravel beach in sections 4 and 6 or delivered to the depositional horn.

Depositional Horn

The depositional horn (section 5) is being formed by waves and currents generated by waves as depicted in figure 6 (orange lines). Given that this is the shape that is naturally forming in this area it makes sense to enhance the process. We can do that by bringing in 1,343 cubic yard of pit run sand and gravels as well as root-wads and logs (Fig. 17 bottom). The material will be placed so that it just extends above full pool lake levels (Fig. 17 bottom). The shape will enhance the circulation patterns and the low elevation will allow spilling breakers to form rather than plunging breaker types. These spilling breakers will carry fine sediments shoreward onto the placed material and deposit that load of sediment as the waves shoal across the depositional horn.

Shore-Attached Gravel beach

The shore-attached gravel beach will be constructed in sections 4 and 5 covering 1,611 lineal feet of shoreline using 3,222 cubic yards of gravel with a 2" to ¾ diameter size range. Approximately 30 root-wads with 20 ft stems will also be placed in strategic locations to create a complex shoreline and to also minimize the longshore transport of gravel. This method of shoreline restoration and erosion control has been used extensively along the North shore of Flathead Lake.

Figure 18. Time-series photographs of a section of eroding marsh shoreline near Bigfork (A May 2007). Photograph B was taken in May 2007 just after placement of the gravel and photograph C was taken in September 2007 showing the accumulation of logs deposited during 2007 storm waves that over-washed the beach. Photograph D was taken in August 2016 showing the accumulation of peat and growth of marsh vegetation over the 11 period.

Figure 18 shows the process over time where a section of shoreline was retreating into the marsh at a rate of 1+ m/yr due to over-wash wave action (Lorang and Stanford 1993). Step one was placement of the material at during April 2007 when the lake was down (Fig. 18 B). After one full pool season (2007) waves during storms deposited many logs and other woody debris (peat) (Fig. 18C). After nearly a decade of storm waves the beach has been nearly completely buried in peat and logs (Fig. 18D) which have allowed recolonization of the beach with a variety of grasses, other herbaceous plants and shrubs, some native and others invasive. During large storms waves still overtop the beach and wash into the marsh maintaining the process connectivity as well as the hydrologic connectivity with the lake. The marsh waters drain through the gravels as the lake level recedes each fall due to lake level regulation. This is what the shoreline will look like in sections 4, 5 and 6 over a period of a decade with perhaps not as much wood as most of the supply delivered by the river ends up further East of the project.

FINAL RENDERING OF THE COMPLETED PROJECT:

The final project, if all sections are built to this design, will look as depicted in Figures 19 and 20. Figure 19 is a plan view that shows the location of the cross-sectional profiles (Figs. 16 and 17) as well as spatial location of other features comprising the site.

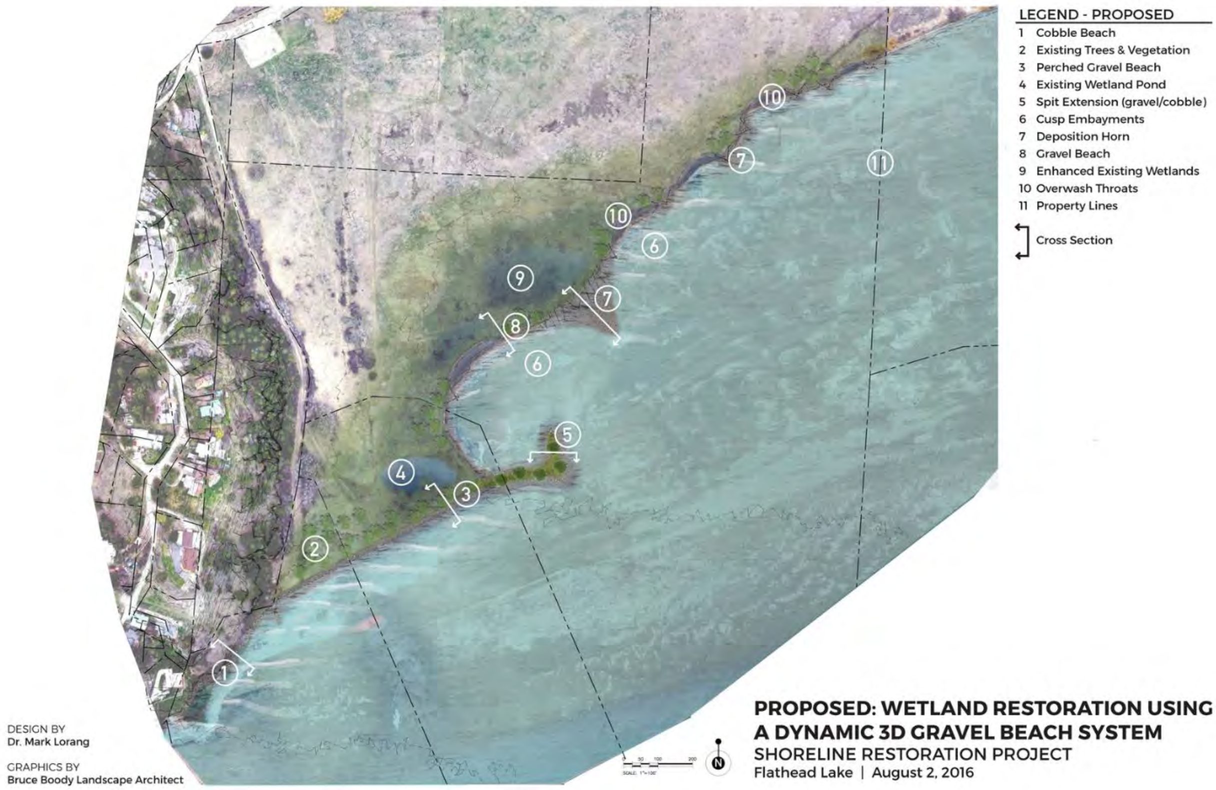

Figure 19. A plan view rendition of the proposed dynamic 3D beach system. Cross-section locations for profiles presented in figures 16 and 17 are shown.

Figure 20. A bird's eye view of the final completed project. Kayakers are drawn to scale.

Acknowledgments:

I wish to thank Chris Barnes of Bruce Boody Landscape Architecture Inc for participating in this project and creating the renderings shown in figures 16,17,19 and 20. They donated nearly half of Chris's time to the project. I would also like to thank Peter Obermeyer, an aspiring Landscape Architect in his senior year at the University of Oregon for traveling here on his own expense to participate in the design from the onset. He created figure 7 which communicates the rationale of very complex wave action on beaches versus seawalls in an extremely effective way that I believe is understandable by a wide audience. The design was by Dr. Mark Lorang who donated his time for this project. Thank you to the Sliter family, especially Tom, I wish you could have seen the final plan.